II. Antiproton Production

A. Main Injector's role

Antiprotons (or pbars) are produced by bombarding a production target with a high energy proton beam. The pbar production rate is dependent on the incident beam energy and, to a much lesser extent, momentum spread. The collection efficiency is dependent on the beam spot size, the gradient of the collection lens and the aperture of the beamline. The beam spot size affects the apparent size of the area from which the secondaries emanate.

An increase in the incident beam energy will result in an increase in yield, but by a diminishing rate after a certain energy threshold is passed. Designers decided to collect a pbar beam of ~8 GeV as that is the peak Booster energy and was the standard injection for the Main Ring. Also, the peak in pbar production from a 120 GeV proton beam is near 8 GeV. A higher energy beam will continue to increase pbar yield, but an incident beam energy of 120 GeV is the best compromise between targeting efficiency, repetition rate and constraints from the transport line. Not coincidentally, 120 GeV falls into the operating range of the Main Injector. The design report calls for the Main Injector to provide 5×10^{12} protons per stacking cycle with a 1.5 second repetition rate. A single Booster batch comprised of 84 53 MHz bunches is accelerated in the Main Injector.

Radio Frequency (RF) manipulations are performed on the beam at 120 GeV just prior to extraction from the Main Injector in a procedure known as bunch narrowing or bunch rotation. This process, shown in figure 2.1, narrows the bunches in time at the expense of increasing the momentum spread ($\Delta p/p$). The $\Delta p/p$ of the antiprotons is minimally effected by the $\Delta p/p$ of the protons. By narrowing the bunches prior to striking the target, the phase space density of the antiprotons is maximized which results in a smaller $\Delta p/p$ in the Debuncher ring after bunch rotation and momentum cooling.

Once the beam reaches flattop in the Main Injector, the RF voltage is quickly lowered and counterphased to an effective 300 kV from its normal value of 4 MV. Main Injector RF cavities have a lower voltage limit of about 20 kV at which point electron multipactoring (sparking) occurs. Counterphasing allows the net RF voltage to be reduced to a lower level. The RF is left at this level for about 2.5 milliseconds while each bunch stretches in time, occupying a large time spread and small momentum spread.

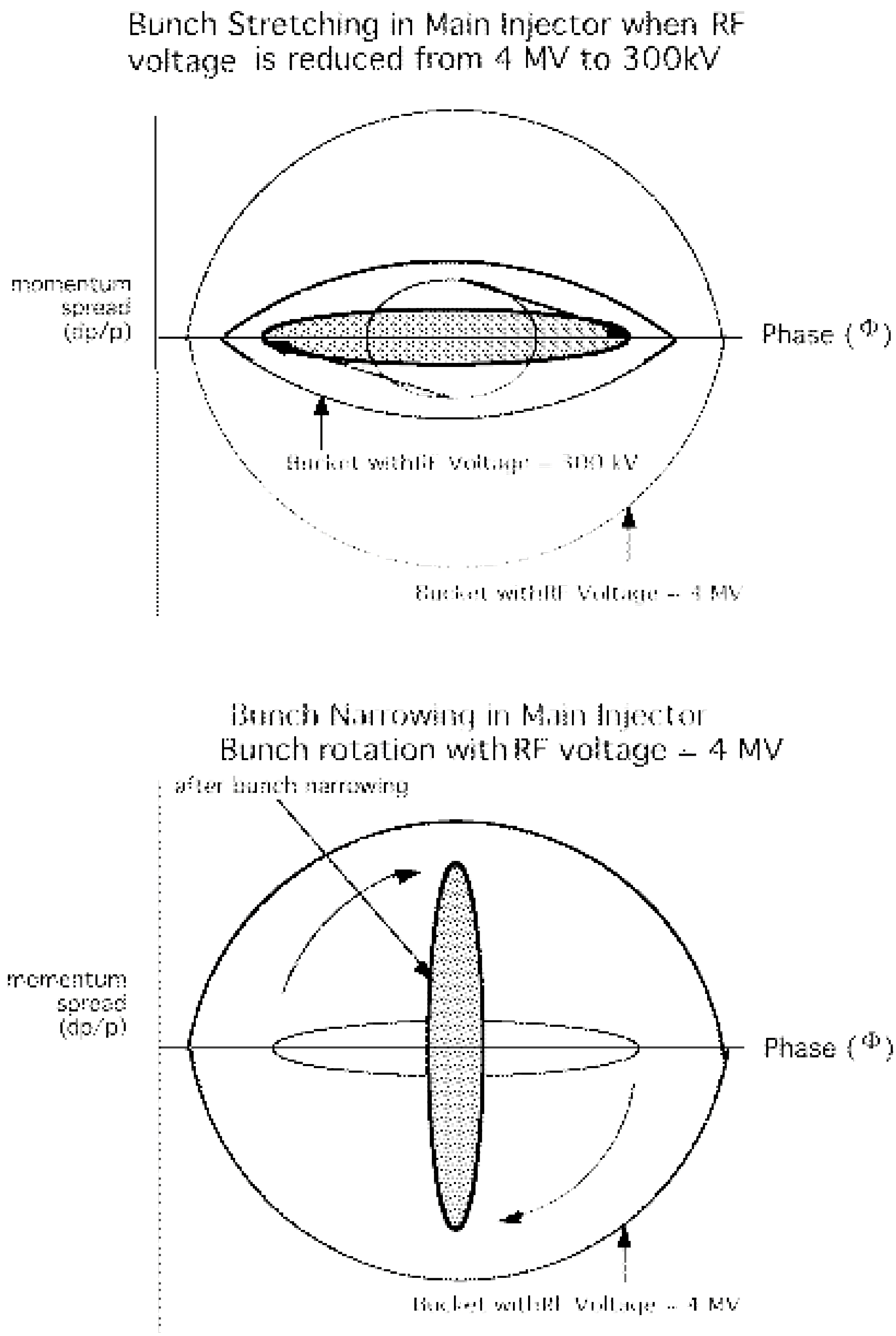

Figure 2.1 RF bunch rotation in the Main Injector

The RF is then quickly increased back to 4 MV. One quarter of a synchrotron oscillation, approximately 1.2 milliseconds later, the bunch has rotated 90° in phase space, reversing the time and momentum spread.

At this time, the beam is extracted from the Main Injector towards the pbar production target. The proton bunches have a small time spread and a large momentum spread. The extraction process is completed in a single turn by means of a fast rise time kicker located at MI-52 followed by a set of three Lambertson magnets. The extracted beam travels down the P1 line, which connects the Main Injector to the Main Ring remnant in the Tevatron enclosure. Beam passes into the P2 line at F0 and follows the path of the old Main Ring to F17. At F17 two Lambertson magnets and a pair of C-magnets bends the beam upward into the AP-1 line. The AP1 line departs the Tevatron enclosure at F18 and continues through the Antiproton source Pretarget and Prevault enclosures before reaching its terminus in the target vault. A toroid, M:TOR109, is located in the AP-1 line just upstream of the target vault to provide a measure beam intensity at the production target.

B. Target station

The actual production and collection of antiprotons occur in a specially designed vault located 17 feet below the AP0 (target) service building. The target station components are hung from 7-foot high steel modules that are suspended into the vault. This arrangement allows easy removal and replacement of faulty components and the steel provides radiation shielding. The major components as seen by the incoming beam are:

Target SEM grid - used to measure the beam position and size just prior to targeting. The SEM has motion control to move the wires out of the beam during normal operation. Beam intensity of more than a few 10^{11} could melt the SEM wires.

Target assembly - a stack of nickel disks, separated by copper cooling disks with channels for air flow to provide heat transfer. Copper targets were used for many years, but nickel can withstand a greater heat deposition before melting. Standard sized target disks are about 10 cm in diameter and 2 cm thick. Some of the targets may be extremely thin, resembling the dimensions of a CD. All disks have a hole in the middle to direct the air flow out of the assembly. The disks are held in a fixture that is encased in a thin titanium jacket. Figure 2.2 shows the cross section of a standard target assembly used during Collider Run 1b.

The horizontal target position is adjustable (D:TRX) so that the amount of target material the beam passes through can be varied. This distance, known as the target length, is one of the parameters that determine the antiproton yield. The target assembly can be rotated so that potential damage to one portion of the target is minimized – depletion of the material is distributed more uniformly through the

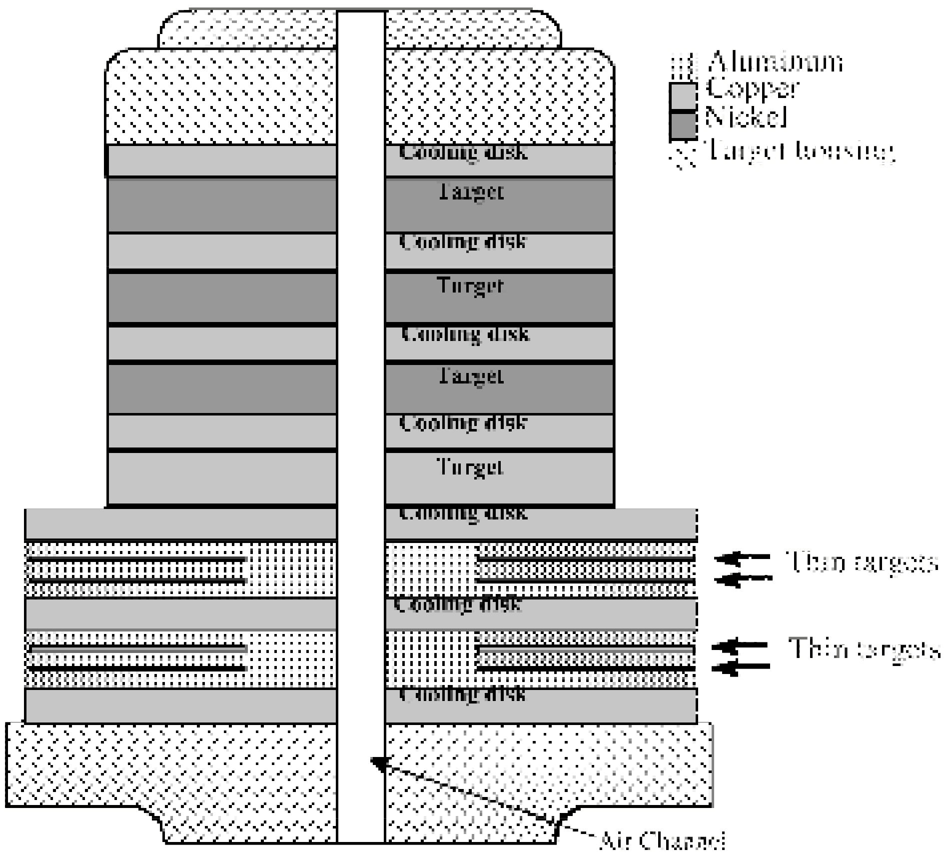

Figure 2.2 Cross section of target assembly

entire target. The rotation is slow, taking many minutes to complete a revolution. Vertical motion control (D:TRY) makes it possible to change the target disk in use (or to take the entire target assembly out of the path of the beam). The position of the target in the z axis (D:TRZ), the distance between the target and lens, can be adjusted to match the diverging cone of secondary particles to the focal length of the Collection lens.

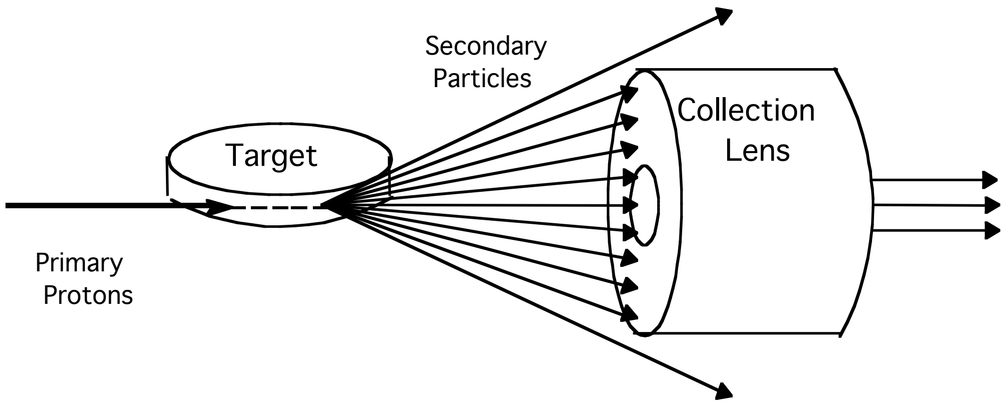

Figure 2.3 Focusing of secondary particles by the Collection Lens

Collection Lens - immediately downstream of the target module is the Collection lens module. The lens is designed to collect a portion of the secondary particles coming off of the target and render them parallel to each other (as illustrated in figure 2.3). Electric current passing through the cylindrical lithium conductor produces a solenoidal magnetic field that focuses the negative secondaries. Lithium was chosen because it is the least-dense solid conductor, which in turn minimizes scattering and absorption. The lens is contained within a toroidal transformer and is designed to operate at a peak current of 670,000A for a gradient of 1,000 Tesla/meter (operationally lenses are run at about 740 Tesla/meter to prolong their life). The transformer is used to step up the current received from the power supply (D:LNV) by a factor of 8 in order to achieve the current required. The lithium conductor is 15 cm long and 2 cm in diameter. The lens body is cooled with a closed loop cooling system. Low Conductivity Water (LCW) from the closed system is heat exchanged with chilled water. A pair of eccentric shafts is used to optimize the horizontal position and angle of the Collection lens.

Pulsed magnet - a 3-degree pulsed dipole follows the lens. Its purpose is to select 8 GeV negatively-charged particles and bend them into the AP2 line. The present magnet design is a single-turn, radiation-hardened, water-cooled, 42-inch long magnet with an aperture measuring 2.13 inches horizontally by 1.13 inches vertically.

Radiation hardening is achieved by using ceramic insulation between the magnet iron and the single winding as well as using Torlon as the insulating material on the bolts, which hold the magnet together. The pulsed magnet achieves a field of 1.5 Tesla. Figure 2.4 shows the pulsed magnet and other devices located in the target vault.

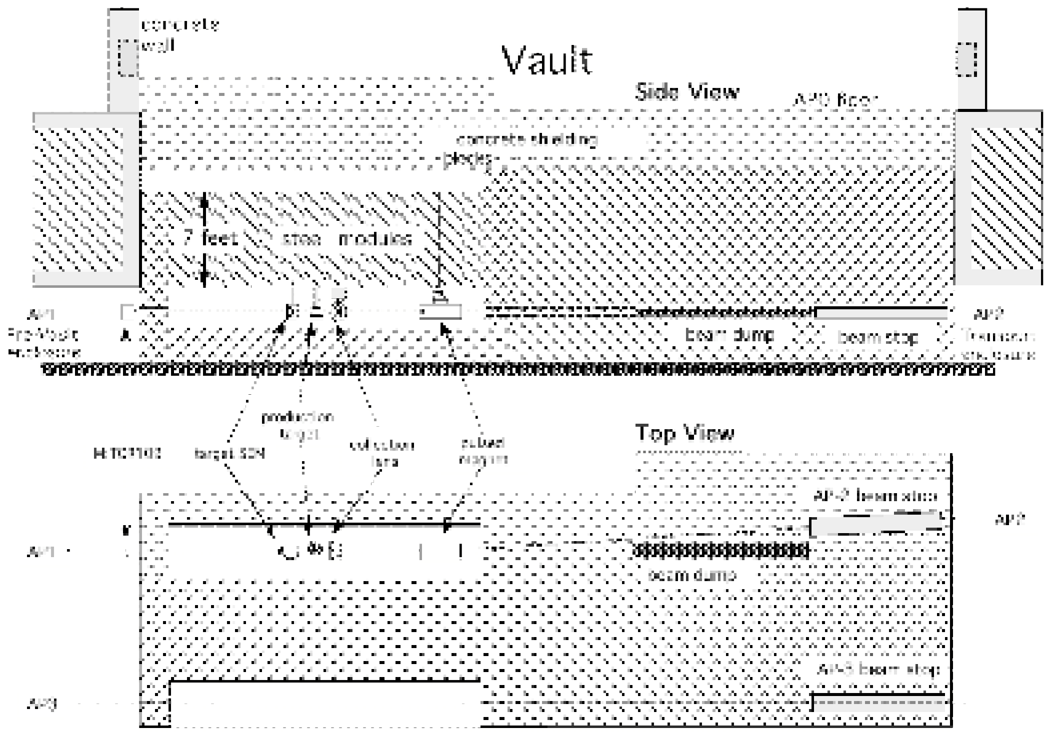

Figure 2.4 Target station components

Beam dump – most of the particles not selected by the pulsed magnet are absorbed by a graphite-core beam dump similar in design to the Tevatron abort dump. The graphite core is incased in an aluminum shell that contains water cooling channels. The graphite and aluminum make up the dump core, which is further contained within several feet of steel shielding. A channel through the steel shield provides an exit for the 8 GeV negative beam and allows it to pass into the AP-2 line. The downstream end of the dump also contains beam stops for the AP-2 and AP-3 lines (D:BSC700 and D:BSC925) which are safety system critical devices and are remotely operable.